

DYNAMIC MODELLING OF CRUDE DISTILLATION UNIT

by

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A thesis submitted to the Faculty of Chemical and Natural Resource Engineering in
partial fulfilment of the requirement for the Degree of Bachelor of Engineering in
Chemical Engineering

Faculty of Chemical and Natural Resources Engineering
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FEBRUARY 2013

TABLES OF CONTENTS

ACKNOWLEDGEMENT	iii
LIST OF TABLE	vi
LIST OF FIGURE	vii
LIST OF FLOW CHART	ix
LIST OF ABBREVIATIONS	x
ABSTRAK	xi
ABSTRACT	xii

CHAPTER 1 INTRODUCTION

1.1 Background of the Proposed Study	1
1.2 Problem Statement	3
1.3 Research Objectives	4
1.4 Scope of the Proposed Study	4
1.5 Significance of the Proposed Study	5
1.6 Conclusion	6

CHAPTER 2 LITERATURE REVIEWS

2.1 Process Mathematical Modeling and Dynamic Modeling	8
2.2 Industrial Characteristic	9
2.3 Refinery Flow Scheme of Crude Distillation Unit	10
2.4 Physical and Chemical Properties of Crude Oil in Malaysia	12
2.5 Choosing a Model for Modeling	16
2.5.1 White Box Model	16
2.5.2 Black Box Model	17
2.5.3 Gray Box Model	18
2.6 Selection of a Thermodynamic Method	19
2.7 Assumption and Simplification	22

CHAPTER 3 METHODOLOGY

3.1	Experiment Design	24
3.1.1	Instrumentation	24
3.2	Procedure	25
3.2.1	Procedure of Forming Mathematical Model	25
3.2.2	Procedure of Steady State Simulation in Aspen Plus	28
3.2.3	Procedure of Dynamic State Simulation in Aspen Plus	31

CHAPTER 4 RESULT AND DISCUSSION

4.1	Mathematical Model	36
4.2	Steady State Simulation	41
4.3	Dynamic State Simulation	53

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1	Conclusion	61
5.2	Recommendation	62

REFERENCES	63
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APPENDICES

APPENDIX A - Steady State Simulation Result	66
APPENDIX B - Dynamic State Simulation Result	68

LIST OF TABLE

		PAGE
Table 2.1	Parameter For CDU (Raja et al, 2010)	11
Table 2.2	Crude Property of Bekok and Labuan Crude Oil (Aspen Hysys, 2001)	14
Table 2.3	Crude Property of Tapis and Miri Crude Oil (Aspen Hysys, 2001)	15
Table 2.4	Recommended Property Method For Difference of System (HYSYS-Basics, 2008)	21
Table 4.1	Steady State Simulation Result of Various Crude Flow rate and Different Type of Crude	41
Table 4.2	Dynamic State Simulation Result of Various Crude Flow rate and Different Type of Crude	54

LIST OF FIGURE

		PAGE
Figure 1.1	Schematic Diagram Of Crude Distillation Unit (Chang, 2006)	3
Figure 2.1	Mathematical Modelling Process (Rick, 2003)	8
Figure 2.2	Schematic Diagram Of A Crude Distillation Unit (Raja Et Al, 2010)	10
Figure 2.3	Typical Yield Of Light And Heavy Crude Oils (ICCT, 2011)	12
Figure 3.1	Overall Block Diagram (Haugen,2010)	25
Figure 3.2	Crude Oil Component Specification Sheet	29
Figure 3.3	Process Flow Sheet Of CDU	30
Figure 3.4	Step Of Changing From Steady State To Dynamic	33
Figure 3.5	Data Require For Dynamic State Simulation	33
Figure 3.6	Export To Aspen Plus Dynamics	34
Figure 4.1	Scheme Of A Column Stage	36
Figure 4.2(a)	Product Flow Rate Versus Bekok Crude Input Flow Rate	43
Figure 4.2(b)	Product Flow Rate Versus Tapis Crude Input Flow Rate	43
Figure 4.2(c)	Product Flow Rate Versus Miri Crude Input Flow Rate	44
Figure 4.2(d)	Product Flow Rate Versus Labuan Crude Input Flow Rate	44
Figure 4.2(e)	Naphtha Flow Rate Versus Crude Input Flow Rate Of Different Crude	45
Figure 4.2(f)	Heavy Naphtha Flow Rate Versus Crude Input Flow Rate Of Different Crude	45
Figure 4.2(g)	Kerosene Flow Rate Versus Crude Input Flow Rate Of Different Crude	46
Figure 4.2(h)	Diesel Flow Rate Versus Crude Input Flow Rate Of Different Crude	46

Figure 4.2(i)	AGO Flow Rate Versus Crude Input Flow Rate Of Different Crude	47
Figure 4.2(j)	Red Crude Flow Rate Versus Crude Input Flow Rate Of Different Crude	47
Figure 4.2(k)	Off Gas Flow Rate Versus Crude Input Flow Rate Of Different Crude	48
Figure 4.2(l)	LVGO Flow Rate Versus Crude Input Flow Rate Of Different Crude	48
Figure 4.2(m)	HVGO Flow Rate Versus Crude Input Flow Rate Of Different Crude	49
Figure 4.2(n)	Residue Flow Rate Versus Crude Input Flow Rate Of Different Crude	49
Figure 4.3(a)	Respond Of Bekok Crude Input Flow Rate Change On ADU Feed, VDU Feed And Residue	55
Figure 4.3(b)	Product Flow Respond On Crude Input Flow Change	55
Figure 4.3(c)	Respond Of Tapis Crude Input Flow Rate Change On ADU Feed, VDU Feed And Residue	56
Figure 4.3(d)	Product Flow Respond On Crude Input Flow Change	56
Figure 4.3(e)	Respond Of Miri Crude Input Flow Rate Change On ADU Feed, VDU Feed And Residue	57
Figure 4.3(f)	Product Flow Respond On Crude Input Flow Change	57
Figure 4.3(g)	Respond Of Labuan Crude Input Flow Rate Change On ADU Feed, VDU Feed And Residue	58
Figure 4.3(h)	Product Flow Respond On Crude Input Flow Change	58

LIST OF FLOW CHART

	PAGE
Flow Chart 3.1 Routes to form a Mathematical Model	27
Flow Chart 3.2 Steady state model process flow chart for Aspen Plus environment	28
Flow Chart 3.3 Dynamic model process flow chart for Aspen Plus environment	32

LIST OF ABBREVIATIONS

ADU	Atmospheric Distillation Unit
API	American Petroleum Institute
BK10	Braun K10
CDU	Crude Distillation Unit
CS	Chao-Seader
GS	Grayson-Streed
HC	Hydrocarbon Component
HVGO	Heavy Vacuum Gas Oil
LPG	Light Petroleum Gas
LVGO	Light Vacuum Gas Oil
MBWR	Modified Benedict Webb Rubin
NRTL	Non Random Two Liquid Model
PR	Peng-Robinson
PRSV	Modified Peng Robinson
SRK	Redlich-Kwong-Soave
TEG	Tri-Ethylene Glycol
VDU	Vacuum Distillation Unit
ZJ	Zudkevitch Joffee

PEMODELAN DINAMIK UNIT PENYULINGAN MINYAK MENTAH

ABSTRAK

Pada masa kini, penggunaan dan permintaan minyak mentah terdapat pertumbuhan yang pesat bagi pelbagai bidang industri. Oleh sebab demikian, harga petrol semakin meningkat kerana permintaan yang jauh lebih tinggi berbanding dengan penghasilan produk petroleum. Dengan maklumat yang sedia ada, kebanyakan model CDU yang digunakan adalah model dalam keadaan mantap. Pertama, prosedur untuk kerja ini adalah membentuk model matematik bagi peringkat teori. Kemudian berdasarkan persamaan separa yang diperolehi, hubungan antara pembolehubah input dan pembolehubah output CDU dikaji. Selepas itu, Aspen Plus Simulasi CDU telah dijalankan dalam mod keadaan mantap dan keputusan yang diperolehi dikaji. Seterusnya, simulasi dinamik CDU dijalankan di Aspen Plus Dynamic dan berdasarkan keputusan yang diperolehi perubahan CDU berkenaan dengan masa dikaji. Sebagai kesimpulan, keputusan yang diperolehi daripada simulasi keadaan mantap telah membuktikan bahawa perubahan keseimbangan tenaga dalam CDU membawa kepada perubahan dalam imbalan jisim CDU. Dari keputusan simulasi dinamik, ia telah menunjukkan perubahan semua pembolehubah proses berkenaan masa sehingga kestabilan sistem dicapai. Satu model dinamik yang baik perlukan untuk menghasilkan satu strategi kawalan yang baik. Oleh itu, kerja ini banyak memanfaatkan dalam memahami perubahan CDU dan boleh digunakan untuk meningkatkan kecekapan proses penapisan dan juga dapat digunakan meningkatkan hasil produk.

DYNAMIC MODELLING OF CRUDE DISTILLATION UNIT

ABSTRACT

There is rapid growth in the usage and demand of crude oil in various industrial fields. Thus, the price of the petrol is rising due to the stronger-than-expected demand for petroleum products. With the available information, most of the modeling models used today is only steady state models. The procedure for this work was firstly forming a mathematical model for the theoretical stage of the column. Then based on the partial equation obtained, the relationship between input variable and output variable was studied. After that, Aspen Plus simulation of CDU was run in steady state mode and the results obtained was studied. Next, a dynamic simulation of CDU in Aspen Plus Dynamic was run and the dynamic behavior of CDU model was studied based on the results obtained. Based on the result obtained from steady state simulation, it was proven that the change of energy balance of the column lead to a change in the mass balance of the column. As the conclusion the dynamic simulation results shown on all the changes of process variable with respect to time until the system stability achieved. A good dynamic model is necessary to develop a proper control strategy. Thus, this work was very helpful in understanding dynamic behaviour of CDU and used to increase the efficiency of refining process which also increases the yield of the product.

CHAPTER 1

INTRODUCTION

1.1 Background of the Proposed Study

Crude oil or known as petroleum is an extremely versatile substance. Crude oil is the formation of different type of hydrocarbon components which need to be passing through a separation process in order to obtain the desired product. From the refining process of crude oil, it creates everything from asphalt and gasoline to lighter fluids and natural gas which containing a variety of essential elements such as sulfur and nitrogen. Apart from that, Crude oil products are also vital feedstock for the purpose of manufacture medicines, chemicals and plastics.

Crude distillation is the first major separation process which also consider as the fundamental process in a petroleum refinery. A Crude distillation unit (CDU) consists of an optional pre-flash distillation column, Atmospheric distillation column

(ADC) and a vacuum distillation column (VDU). The petroleum products obtained as Chang (2006) reported from the distillation process are light, medium and heavy naphtha, kerosene, diesel, atmospheric gas oil (AGO), light vacuum gas oil (LVGO), heavy vacuum gas oil (HVGO) and oil residue. To date, there are various academic contributions on the analysis of crude distillation system. Those research of analysis can be dovetailed into three major area which are heat exchanger networks associated to CDU (Plesu et al., 2003; Gadalla et al., 2003), refinery planning and scheduling (Cao et al., 2009; Rivero et al., 2004) and crude distillation modelling, simulation and optimization (Inamdar et al., 2004; Liao et al., 2004; Dave et al., 2003; Kumar et al., 2001; Seo et al., 2008). Study and analyze the actual performance of the crude distillation column is beneficial in order the industrial to achieve the highest efficiency which can help to lower down the cost of operating of the product thus may help reduce the price of the petroleum products.

In this research the model of CDU used consist of a pre-flash column followed by atmospheric distillation column and vacuum distillation column. The basic model schematic diagram of CDU is shown in Figure 1.1.

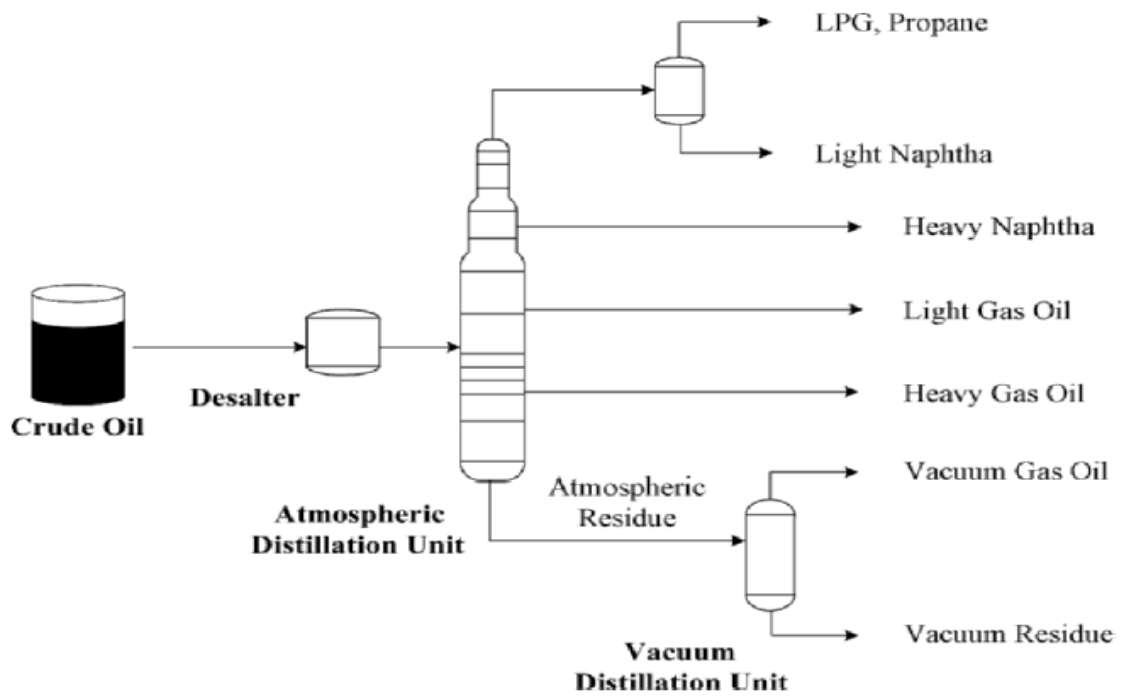


Figure 1.1 Schematic Diagram of Crude Distillation Unit

(Source: Chang, 2006)

1.2 Problem Statement

There are rapidly growth in the usage, and demand of crude oil in industries field such as medicines, chemicals, plastics and as fuel for vehicle. However, there is a limited supply available the worldwide market. Therefore, the price of the petrol gave rise due to the stronger-than-expected demand for petroleum products.

Other than that, the dynamic model of crude distillation unit need to be study clearly and known in order to obtain a high efficiency refining process which can increase the yield of the petroleum product. A proper control system can be develop by understand the dynamic behavior of CDU.

However as what information available nowadays, most of the other researchers are only focus on steady state modeling. Hence, the research on dynamic modeling for CDU is required so that it can be the atom to initiate the other researcher to explore and study more in this section.

1.3 Research Objectives

There are two main objectives of conducting this study

- 1.3.1 To develop a dynamic model of CDU based on the steady states CDU model.
- 1.3.2 To study the effect of different operating conditions of petroleum refining toward the yield and composition of petroleum products by solving model equations.

1.4 Scope of the Proposed Study

The scope of this study is to study the interaction between the mass balance, component material balance and heat balance. The formula of mass balance, component material balance and heat balance is used to build up a mathematical model for the petroleum refining process. The mathematical model can be described the relationship between input variable and output variable by an ordinary or partial differential equation.

A part from that, the scope of this proposed study also include the study on the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product. A mathematical equation that form from mathematical model is needed to find an appropriate method to solve the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product.

Thus, a dynamic model of CDU will be developed based on the steady states CDU model. The steady state CDU model is used on the study of dynamic behaviour of CDU thus to find the simulation result under dynamic condition. The simulation result obtained will be compare with the plant data available in literature.

1.5 Significance of the Proposed Study

The significance of this study is the study of dynamic behaviour of the CDU model. A good dynamic model is necessary to develop a proper control strategy. A part from that, this study is very helpful for the understanding of dynamic behaviour of CDU and this study can act as an atom which will initiate the development of CDU. It is because this study involves the study of interaction between the mass balance, component material balance and heat balance which will show the relationship between the input variable and the output variable.

1.6 Conclusion

The main aim of this study is study about the dynamic behaviour of the CDU model. Therefore, this proposed study is very helpful in understanding dynamic behaviour of CDU. Thus, this proposed study also can be an atom to initiate the development of CDU in order to find a proper control strategy. Furthermore, this study also aims on the effect of different operating condition of petroleum refining toward the yield and composition of petroleum product through the study of the interaction between the mass balance, component material balance and heat balance which is helpful to understand clearly the relationship between the balance law, input and output variable. As conclusion, this study can act as an atom to the development of dynamic model of CDU.

CHAPTER 2

LITERATURE REVIEW

In recent years, the demand for petroleum products is rapidly rise. For example, in 2005, each of the estimated 296 million people in the U.S. used an average of almost three gallons of petroleum every day. In 1978, the average American used 3.5 gallons per day mixture. (U.S Energy Information Administration, 1979)

Distillation is a method used for separate component from a liquid mixture based on their relative volatilities. Unlike purely mechanical separations, distillation methods utilize the differences in vapour pressure or boiling point of each component but not density or particle size. The distillation column provides an environment where the liquid and the vapour phase can achieve equilibrium within the column. When the mixture is heat up, the higher volatility component will be

evaporated first. The appearance of gas phase is due to the vaporization process of a component at its boiling temperature. (McCabe, 1967)

2.1 Process Mathematical Modelling and Dynamic Modelling

Mathematical Modelling is an important part of process design economically. It is because, modelling involve the conceptual synthesis of the process flows sheet, detailed design of specialized processing equipment and the design of the process control systems. Other than that, Mathematical model is also used to investigate the source of problem. Then important factors will be determined and those factors will be interplay as in a mathematical way. Then the mathematical relationships will be analyzed. After all, mathematical model is an evaluation of how to applicable the results obtained into the real-world situation. (Rick, 2003).

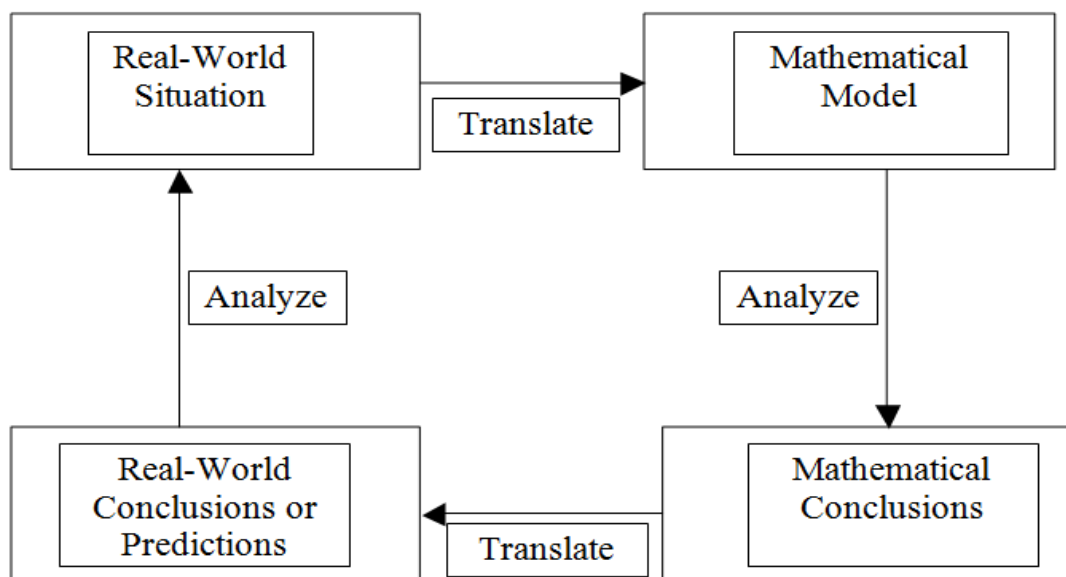


Figure 2.1 Mathematical Modelling Process

(Source: Rick, 2003)

The core study of dynamic modelling is the study on the dynamic behaviour. Dynamic behavior is the behavior describes of a distributed parameter in a system. The behavior describe is in terms of how one qualitative state affect another. A qualitative state is described by a static model. For example, it describes the distributions and intersections of the qualitative fields at a particular time instant or interval. (Monika, 1997)

2.2 Industrial Characteristic

As mentioned before, Crude distillation is the first major separation process which also consider as the fundamental process in a petroleum refinery. The petroleum obtained from different oil farm consists of different hydrocarbon composition combination. Chang, (2006) stated that petroleum was form from the bodies of ancient organisms such as died animals and plants and over time those body was transformed into simple chemicals compound. Therefore, each petroleum fields have their unique operating condition due to different combination of composition inside the crude.

As stated by ICCT at 2011, there was more than 660 refineries, in 116 countries, are currently in operation and producing more than 85 million barrels of refined products per day. Thus, each refinery have its own unique processing method, configuration and performance which based on the crude oil characteristics,

process equipment available, operation costs, refinery's location, vintage, availability of funds and product characteristic demand.

2.3 Refinery Flow Scheme of Crude Distillation Unit

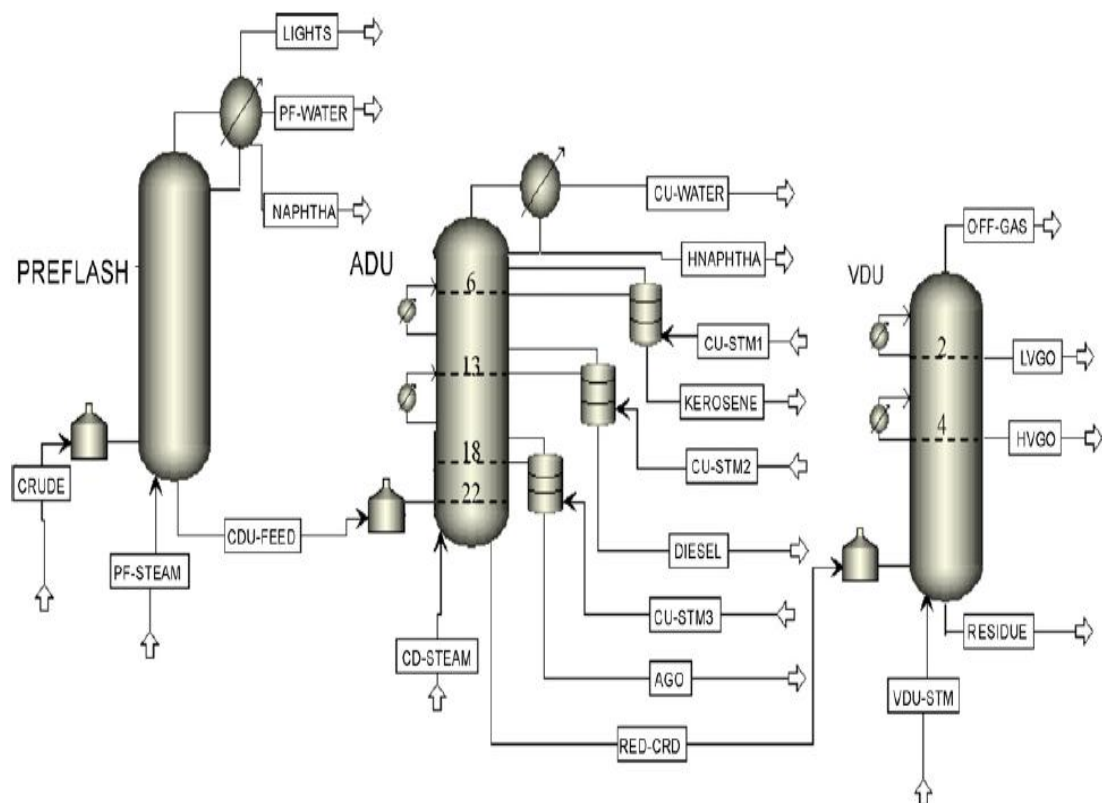


Figure 2.2 Schematic Diagram of a Crude Distillation Unit

(Source: Raja et al, 2010)

Table 2.1 Parameter for CDU

Parameters		Value	
1) Preflash Unit			
No of Stages	10		
Pressure	273.7 kPa	(top stage)	
	308.2 kPa	(bottom stage)	
Temperature	232°C		
Condenser Temperature	77 °C		
Condenser Pressure	274 kPa		
Condenser Pressure drop	14 kPa		
2) ADU			
No of Stage	25		
	22	(feed stage)	
Pressure	108.2 kPa	(top stage)	
	170.3 kPa	(bottom stage)	
	28 kPa	(pressure deop)	
Pump Around			
Pump Around 1	Stage 8 – Stage 6		
Heat Duty	-11.7 MW		
Pump Around 2	Stage 14 – Stage 13		
Heat Duty	-4.4 MW		
Side Stripper			
Kerosine Stripper	4 Equilibrium Stages		
	Stage 6 – Stage 5		
Diesel Stripper	3 Equilibrium Stages		
	Stage 13 – Stage 12		
AGO Stripper	2 Equilibrium Stages		
	Stage 18 – Stage 17		
3) VDU			
No of Stage	6		
	5	(feed stage)	
Pressure	8.0 kPa	(top stage)	
	9.3 kPa	(bottom stage)	

(Source: Raja et al, 2010)

2.4 Physical and Chemical Properties of Crude Oil in Malaysia

Crude oil can be classified into light crude and heavy crude. Those “light” or “heavy” is a characteristic representative of crude oil’s density which based on the American Petroleum Institute (API) gravity. This API gravity value is the comparison of oil with water which reflects the “Light” or “heavy” of crude.

As addressed in an Introduction to Petroleum Refining and The Production of Ultra Low Sulphur Gasoline and Diesel Fuel by ICCT in 2011, the value of API gravity 10 is the base of water. The crude with API more than 10 than the crude will float on the water, if the crude with API less than 10 than the crude will sink. The lighter the crudes, the easier and less processing cost. It is because the lower API gravity value represent that higher percentage of light hydrocarbon is contained in the crude which will require more simple distillation process at a petroleum refinery. Figure 2.3 below show the quality of a light and heavy crude, in term of the natural yield of light gas, gasoline, distillate (kerosene, diesel) and heavy oil and the average demand for these product categories in a developed countries.

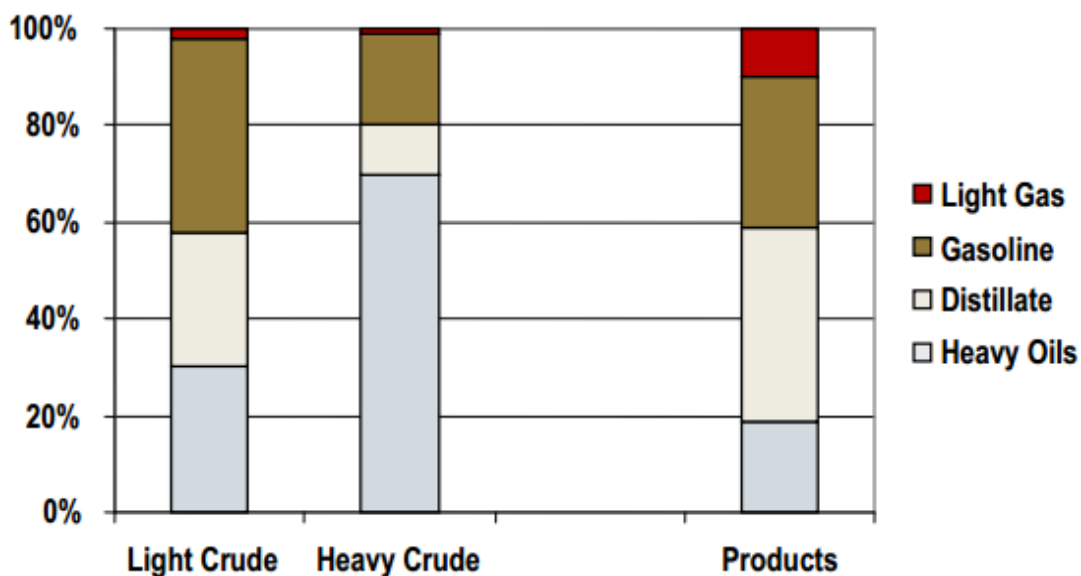


Figure 2.3 Typical yield of light and heavy crude oils

(Source: ICCT, 2011)

In general, the densities of Malaysia crude oil field have almost the same density to some of the crude oils in Norwegian Continental Shelf which the densities vary in between 0.79 to 0.98 g/cm³ at 15°C ± 5°C from thesis of Formation and Stability Study of Some Malaysian Crude Oil Emulsions which the authors are Ariany in year 2004.

In this research, the methodology involves changing the operating crude oil inlet flow rate and composition of the crude feed by change type of crude oil. For running the Aspen Plus software, the requirement of changing the crude composition is API, distillate percentage and crude density. The API is difference for each source of crude. Therefore, difference type of Malaysian crude properties of Malaysia oil field is obtained. For example, the crude oil for Bekok, Labuan Sarawak, Tapis and Miri Sarawak. Table 2.2 and Table 2.3 below are identifies API, distillate percentage and mid percentage API of crude oil field Malaysia from Aspen Plus Data Storage.

Table 2.2 Crude Property of Bekok and Labuan Crude Oil

Types of Malaysian Crude	Bekok		Labuan Sabah	
API	49.07		33.2	
	Percentage distillate	Temperature (F)	Percentage distillate	Temperature (F)
	2.7	68	0.97	68
	9.75	145	2.97	145
	36.51	330	21.77	330
	52.25	450	39.77	450
	78.38	650	78.04	650
	80.38	680	81.04	680
	96.23	975	97.87	975
	Mid Percentage	API gravity	Mid Percentage	API gravity
	65.32	41.65	30.77	38.7
	72.98	38.71	40.15	35.56
	88.3	32.84	58.9	29.27
	89.19	31.54	89.45	15.79

(Source: Aspen Technology, 2009)